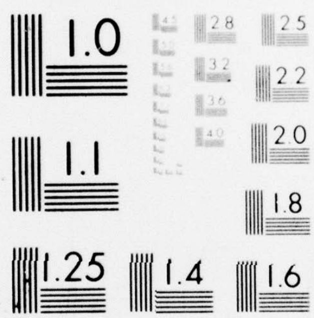
AD-A034 771 UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES ELECTR--ETC F/G 20/5
X-RAY LASER STUDIES.(U)
OCT 76 W H LOUISELL, J F SEELY DAAG29-76-G-0076
UNCLASSIFIED ARO-13602.6-R-P NL

1 OF 1
AD
A034771

END
DATE
FILMED
2-77



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ARO-13602.6-R-P

ADA034771

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ARO-13602.6-R-P
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): X-RAY LASER STUDIES
5. TYPE OF REPORT & PERIOD COVERED: Final Report: 15 Oct 75 — 28 Oct 76
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): William H. Louisell, John F. Seely
8. CONTRACT OR GRANT NUMBER(s): DAAG29-76-G-0076
9. PERFORMING ORGANIZATION NAME AND ADDRESS: University of Southern California, Los Angeles, California 90007
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

28 Oct 76

11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709
12. REPORT DATE: 1976

10p.

13. NUMBER OF PAGES: 7
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

X-Rays, Lasers, Ion Beams, Charge transfer, Pumping, Excitation, Mercury, Cesium, Vacuum ultraviolet radiation, Helium, Coherence, Laser amplifiers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Topics of this theoretical study are swept ion beams and quasi-steady-state excitation.

A listing of papers in various stages of publication is provided.

410 013

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

13602.6-R-P

Post LRCP Grant

Final Technical Report

1. ARO PROPOSAL NUMBER: P-13602-R-P

2. PERIOD COVERED BY REPORT: 15 October, 1975-30 June, 1976

3. TITLE OF PROPOSAL: "X-Ray Laser Studies"

4. CONTRACT OR GRANT NUMBER: DAAG29-76-G-0076

5. NAME OF INSTITUTION: University of Southern California

6. AUTHOR(S) OF REPORT: William H. Louisell and John F. Seely

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

See Report

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Dr. John F. Seely, Research Associate

Dr. W. H. LOUISELL
ELECTRONIC SCIENCES DIVISION
UNIVERSITY OF SOUTHERN CALIFORNIA
LOS ANGELES, CA 90007

1360 2P

Manuscripts Submitted or Published Under ARO

Sponsorship During Grant Period Oct. 15-June 30, 1976

1. W. H. Louisell, J. F. Seely, R. Shnidman and M. Lax, "A Swept Focus Scheme for an Ion Beam X-Ray Laser," accepted for publication in Jour. Appl. Phys.

2. J. F. Seely, W. H. Louisell, R. R. Bouslk," Coaxial Sweep Scheme for Ion-Beam Lasers," IEEE Jour. Quant. Elect. 515-517, August, 1976.

3. "Review of Soft X-Ray Lasers Using Charge Exchange," in Progress in Lasers and Laser Fusion, ed. by B. Kursunoglu, A. Perlmutter and S. M. Widmayer, Plenum Pub. Co., New York, pp. 147-234, 1976.

4. J. F. Seely, "Mercury-Cesium Vacuum-UV Laser Using Charge Exchange Pumping," (to be published in Journal of Appl. Phys. Jan. or Feb. 1977).

5. D. Anderson, J. McCullen, M. O. Scully and J. F. Seely, "Analysis of Short-Wavelength Charge Exchange Lasers Via Plasma-Gas Beam Clashing," Opts. Comm., 17, 226-230, (1976).

6. F. A. Hopf, P. Meystre, M. O. Scully, and J. F. Seely, "Coherence Brightening and Laser Lethargy in X-Ray Laser Amplifiers," Phys. Rev.Lett., 35, 511-513, (1975).

7. J. F. Seely, "Numerical Rate Equation Model for the He-Cs Charge Exchange Laser," Los Alamos Informal Report, LA-6298-MS, April, 1976.

I. SWEPT ION BEAM SCHEMES

The lifetimes of the upper states of proposed charge-exchange x-ray lasers are typically in the sub-nanosecond range, implying that tremendous pump rates are needed to overcome spontaneous decay losses. In order to mitigate these spontaneous decay losses, Scully, Louisell, and McKnight[1,2] suggested using a modification of McCorkle's[3] ion beam sweep scheme to produce lasing on the 304 Å line of He^+ as a result of the reaction

$$He^{++} + H \rightarrow He^+ (2p) + H^+, \tag{1}$$

After analyzing the pickup of electrons by α particles incident on a hydrogen foil target, they concluded that the thickness of the foil would have to be of order 10 Å to prevent double-electron pickup and de-excitation collisions. Also the Doppler width is relatively large ($\Delta\omega_D \sim 10^{12}\ S^{-1}$) due to multiple scattering. In contrast, the Doppler width for a gaseous hydrogen target ($N \sim 10^{16} - 10^{17}\ cm^{-3}$) was estimated to be only $2 \times 10^{10}\ S^{-1}$, or twice the homogeneous linewidth. Thus, the gaseous hydrogen target offers significant advantages compared to the foil target.

The laser gain for the case of a gaseous target was calculated using the equation[2]

$$g = (3/2)(\ln 2/\pi)^{1/2} (\lambda^2\, \Delta\omega_s i\, \Delta P \ell/\Delta\omega_D\, qV_o\, \Delta x \Delta y) \cdot e^{\beta^2} (1 + \mathrm{erf}\, \beta), \tag{2}$$

where $\beta = (\ln 2)^{1/2}\, \Delta\omega_s/\Delta\omega_D$. The ion beam parameters were taken to be $i = 30$ mA, $V_o = 9.8 \times 10^7$ cm/s, $q = 2e$, and $\Delta x \Delta y = 5.5 \times 10^{-5}\ cm^2$. For an inversion $\Delta P = .05$ over length $\ell = 10$ cm, the gain is 47. While this value looks promising, there are two major problems with the calculation. The most obvious problem is the extremely small ion beam area ($5x5 \times 10^{-5}\ cm^2$) used in the calculation. Considering only the effect of the finite emittance of the ion source, the emittance - limited focal area is given by Langmuir's expression[6]

$$A = f^2 (\epsilon_{th}/\epsilon_o) \tag{3}$$

where f is the focal distance, ε_{th} represents the thermal energy of the ion source, and ε_o is the acceleration energy. Equation (3) is derived under very general assumptions and represents the absolute best focusing that one could hope for. In actual practice, this ideal limit is never attained.[4] Using $f = 10$ cm, $\varepsilon_{th} = 1$ eV, and $\varepsilon_o = 40$ keV, we find a focal area of $A = 2.5 \times 10^{-3}$ cm^2, nearly 50 times larger than the assumed value 5.5×10^{-5} cm^2.

The second major problem with the gain calculation of Ref. 2 is that the effect of the lethargic response[5] of the active medium to the gain pulse was not included. When the Doppler broadening is small, the response time of the polarization of the laser medium to the pump pulse is given by the inverse homogeneous linewidth. After the pump pulse ceases, the population inversion decays on this same timescale. If the duration of the pump pulse is small compared to the spontaneous lifetime as in Ref. 2, the growth and decay rates of the gain are nearly equal, and the value given by Eq. (2) is not attained. In the case $\Delta\omega_D \sim \Delta\omega_s$, the gain expression (2) should be multiplied by the factor[6]

$$e^{-\Delta\omega_s \mu} \operatorname{erf}(\alpha \mu), \qquad (4)$$

where $\alpha \sim \Delta\omega_s$ and $\mu = t-x/c$. Thus, expression (2) is reduced by about a factor of 3. It has been noted[5,6] that in swept-gain systems, the atoms are excited just as the radiation pulse arrives, and so the cooperation length of the laser medium is infinite. The laser radiation field is enhanced due to coherence brightening after traveling 15-20 cm, and the detrimental effects of laser lethargy are somewhat mitigated in long active media.

Due to the neglect of emittance, space charge, laser lethargy, fringing fields, and a host of other effects, the gain calculations of Refs. 1 and 2 are probably too large by several orders of magnitude. The swept-focus scheme of Ref. 7 is characterized by an ion beam focal length of 70-80 cm, so emittance effects are an order of magnitude more troublesome. It has been suggested that the high-brightness liquid metal ion source[8] might alleviate some of the beam

focusing problems. But this is effectively a point source, and the beam radius blows up tremendously as the ions follow the field lines radiating outward from the point source.[9] Also, the source temperature is rather high (12 eV; Ref. 8). It has been demonstrated that this source can produce a 100 μ A ion beam of high brightness,[8] but scaling this up to the tens of milliamperes needed for laser applications is doubtful.[9]

A coaxial focusing scheme in which the ion beam is initially in Harris[10] flow has been proposed.[11] The ion beam propagates between the electrodes of a coaxial transmission line, and space-charge blowup and thermal spreading is prevented by a constant electric field between the coaxial electrodes. Application of a voltage pulse to the coaxial transmission line focuses the ion beam toward the inner electrode where the target is positioned. Experimental implementation of this scheme would be difficult due to the poor accessibility of the inner electrode region where lasing occurs. The positioning of a dense, pulsed gaseous target in this confined region would be a formidable task.

II. QUASI-STEADY-STATE EXCITATION

It has been noted[6] that the large ion densities produced by plasma guns are attractive for x-ray laser application. The system would be easier to implement due to the absence of focusing and sweeping requirements, and blowup is alleviated by the neutral property of the plasma and the short propagation distance between source and target. In addition, the laser is strongly Doppler broadened ($\Delta\omega_D \sim 10^{12} - 10^{13}\ s^{-1}$) due to the high plasma temperature, so laser lethargy should not be a consideration.

A numerical rate equation analysis has been performed[12] for the case of a helium plasma incident on a cesium target. The pump reaction is

$$He^+ Cs \rightarrow He^* (2p) + Cs^+ , \tag{5}$$

where the cross section is $2 \times 10^{-15}\ cm^2$ at 1 keV ion energy. After consideration

of the collisional reaction that are likely to compete with the pump reaction, it was concluded that excitation of the cesium atoms by plasma electron impact ($\sigma = 9 \times 10^{-15}$ cm^2) was the most damaging. That is, the plasma electrons might destroy the cesium ground state population on which the pump reaction (5) depends. Indeed, this was the case in the numerical results when the target density was the same order of magnitude as the plasma density ($n \sim 10^{16}$ cm^{-3}). But when the target density is much greater than the plasma density, the results are entirely different. In this case, the plasma electrons ($n \sim 10^{16}$ cm^{-3}) destroy only a small fraction of the cesium ground state density (initially $n \gtrsim 10^{18}$ cm^{-3}), and sufficient cesium neutrals remain in the interaction region for the pump reaction to proceed. Laser intensities of order 10^6 W/cm^2 are calculated[12,13]. The numerical results are in agreement with a simple analytical model.[13]

When the plasma ions are incident on the gaseous target, they pick up electrons into the upper laser state. As the excited ions travel deeper into the target, spontaneous and stimulated processes fill the lower laser state. Thus, beyond about 0.2 mm from the target edge, the gain is negative. It is therefore necessary that the face of the target be flat to within 0.2 mm along the length of the laser axis. Otherwise, the laser photons will pass through the region of negative gain and be absorbed. The gain is found to be proportional to the slope of the target density profile, that is, proportional to the rate of buildup of cesium atoms in the interaction region.[13] Thus, the operation of the laser depends upon the existence of a flat, steep target density profile; the characteristics of the initial plasma density profile are of secondary importance. These requirements together with the high density ($n \gtrsim 10^{18}$ cm^{-3}) imply a pulsed target produced by vaporization from a flat plate or wire. Numerical studies of the expansion of such a target indicate that density profile slopes of $n/d \sim 10^{19}$ cm^{-4} should be obtainable.[11]

It has been suggested that the reaction

$$Hg^{+} + Cs \rightarrow Hg^{*} (^{1}P_{1}) + Cs^{+} \tag{6}$$

may be used to pump a vacuum uv (1849 Å) laser.[14] Partly due to the relatively large charge-exchange cross section (5.5×10^{-15} cm^2 at 10 keV) and the relatively small Doppler width ($m_{Hg}/M_{He} = 50$), the laser gain is three orders of magnitude larger than for the reaction (5). This relaxes the requirements on the ion density and gaseous target, and a numerical rate equation analysis indicates that laser operation may be achieved using a conventional Penning ion source ($n \sim 10^{12}$ cm^{-3}) and oven-generated cesium target ($n \sim 10^{16}$ cm^{-3}). Since an ion source rather than a plasma source is used, destruction of the gas target by hot electrons is not a consideration. Quasi-cw laser intensity of order 100 W/cm^2 is calculated.[14]

REFERENCES

(Publications supported by this contract are indicated by * and are included in the appendix)

1. M. O. Scully, W. H. Louisell, and W. B. McKnight, Opt. Comm. 9, 246 (1973).

2. W. H. Louisell, M. O. Scully, and W. B. Mcknight, Phys. Rev. A10, 989 (1957).

3. R. A. McCorkle, Phys. Rev. Lett. 29, 982 (1972) and 29, 1428 (1972).

4. R. Wilson and G. Brewer, Ion Beams, (1973), p. 147.

*5. F. A. Hopf, P. Meystre, M. O. Scully, and J. F. Seely, Phys. Rev. Lett. 36, 511 (1975).

*6. C. D. Cantrell, M. O. Scully, W. H. Louisell, J. Seely, et al., in Progress in Lasers and Laser Fusion, ed. by B. Kursuneglu, A. Perlmutters. S. Widenayer (Plenum, New York, 1975).

*7. W. H. Louisell, J. F. Seely, R. Shnidman, and M. Lax, J. Appl. Phys. (accepted for publication).

8. V. E. Krohn and G. R. Ringo, Appl. Phys. Lett. 27, 479 (1975).

9. W. H. Louisell and F. S. Seely (unpublished).

10. L. A. Harris, Proc. IRE 40, 700 (1952).

*11. J. F. Seely, W. H. Louisell, and R. Bousek, IEEE J. Quant. Electr. (accepted for publication).

*12. J. F. Seely, Los Alamos Scientific Laboratory Report LA-6298-MS (1976).

*13. D. Anderson, J. McCullen, M. O. Scully, and J. F. Seely, Opt. Comm. 17, 226 (1976).

*14 J. F. Seely, "Mercury-Cesium Vacuum-UV Laser Using Charge Exchange Pumping," J. Appl. Phys. (accepted for publication).

APPENDIX

Publications supported by this contract and included in this Appendix are:

a. "Coherence Brightening and Laser Lethargy in X-Ray Laser Amplifiers", F. A. Hopf, P. Meystre, M. O. Scully, and J. Seely, Phys. Rev. Lett. 35, 511 (1975).

b. "Review of Soft X-Ray Lasers Using Charge Exchange", C. D. Cantrell M. O. Scully, W. H. Louisell, J. Seely et al., in Progress in Lasers and Laser Fusion, ed. B. Kursunoglu, A. Perlmutter, and S. Widmayer (Plenum Press, New York, 1975).

c. "Swept Focus Scheme for an Ion Beam X-Ray Laser", W. H. Louisell, J. F. Seely, R. Shnidman, and M. Lax, J. Appl. Phys. (accepted for publication).

d. "Coaxial Sweep Scheme for Ion-Beam Lasers", J. F. Seely, W. H. Louisell, R. Bousek, IEEE J. Quant. Electr. (accepted for publication).

e. "Numerical Rate Equation Model for the He-Cs Charge Exchange Laser", J. F. Seely, LASL Report LA-6298-MS (1976).

f. "Analysis of Short-Wavelength Charge-Exchange Lasers via Plasma-Gas Beam Clashing", D. Anderson, J. McCullen, M. O. Scully, and J. F. Seely, Opt. Comm. 17, 226 (1976).

g. "Mercury-Cesium Vacuum-UV Laser Using Charge Exchange Pumping", J. F. Seely, J. Appl. Phys. (accepted for publication).